Renewable and Sustainable Energy Reviews 14 (2010) 404–412

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Assessment of externalities related to global and local air pollutants with the NEEDS-TIMES Italy model

F. Pietrapertosa [a,*], C. Cosmi [a], S. Di Leo [c], S. Loperte [a], M. Macchiato [b], M. Salvia [a], V. Cuomo [a]

[a] National Research Council, Institute of Methodologies for Environmental Analysis, C.da S. Loja, I-85050 Tito Scalo (PZ), Italy
[b] Federico II University, Dept. of Physical Sciences, Via Cintia, I-80126 Naples, Italy
[c] University of Basilicata, Dept. of Environmental Engineering and Physics, C.da Macchia Romana, I-85100 Potenza, Italy

ARTICLE INFO

Article history:
Received 16 June 2009
Accepted 10 August 2009

Keywords:
Energy system model
TIMES models generator
External costs assessment
Scenario analysis
NEEDS project

ABSTRACT

This work is aimed to illustrate the potentiality of the multi-region NEEDS-TIMES modelling platform, in the economic evaluation of the environmental damages due to air pollution. In particular the effects of external costs on the least-cost optimised energy system configuration were analysed in a national case study with the NEEDS-TIMES Italy model, considering the externalities related to local and global air pollutants (NO_x, SO_2, VOC, particulates and GHGs). Different scenarios were compared to emphasise the role of external costs in the achievement of strategic environmental targets. The main results obtained are discussed, focusing on the changes in energy fuel mix as well as in local air pollutants and GHG emissions, highlighting the main conclusions in terms of policy strategies.

Contents

1. Introduction 404
2. Methods 405
   2.1. The NEEDS-TIMES energy models 405
   2.2. Computation of the environmental damages 405
3. The case study 406
   3.1. Energy consumption 406
   3.2. Air emissions 406
   3.3. National renewables potentials 406
   3.4. CO_2 reduction potential 407
   3.5. Integration of external costs into the Italian model 407
      3.5.1. External costs of local air pollutants (LAP) 407
      3.5.2. External costs of greenhouse gases (GHGs) 407
4. Scenario analysis 408
5. Conclusive remarks 410
   Acknowledgements 411
   References 411

1. Introduction

Recent advances in energy systems modelling allow supporting effectively the development and the coordination of energy–environmental strategies at local, national and multi-country scale, pointing out technical choices as well as economic aspects and environmental consequences of possible alternatives on the medium-long term.

* Corresponding author. Tel.: +39 0971 427 207; fax: +39 0971 427 271.
E-mail addresses: fpietra@imaa.cnr.it (F. Pietrapertosa), cosmi@imaa.cnr.it (C. Cosmi), dileo@imaa.cnr.it (S. Di Leo), sloperte@imaa.cnr.it (S. Loperte), macchiato@na.infn.it (M. Macchiato), salvia@imaa.cnr.it (M. Salvia), cuomo@imaa.cnr.it (V. Cuomo).

1364-0321/$ – see front matter
doi:10.1016/j.rser.2009.08.011

A main role in this field is played by the Energy Technology Systems Analysis Programme (ETSAP [1]), an Implementing Agreement of the International Energy Agency (IEA), which is aimed to establish, maintain, and expand technical-economic tools for supporting the definition of sustainable strategies for economic development, energy security, climate change mitigation and environmental protection at the global, regional, national and local levels.

Currently, a key issue in the definition of energy–environmental strategies is to take into account the negative externalities on environment and health due to anthropogenic pollution in order to evaluate their role in the achievement of sustainability targets and to fair prices of resources and services making them inclusive of these extra charges.

In this framework, both Life Cycle Assessment (LCA) and ExternE methodologies have given a valuable contribution to estimate the damages caused by the energy uses, the former being aimed to evaluate the overall environmental burdens associated with the life cycle of products, processes or activities [2], and the latter in the monetary evaluation of their indirect effects on health and environment [3].

The external costs can be "internalised" by introducing eco-taxes (i.e. by taxing fuels and technologies according to the damages caused), or subsidising cleaner technologies in order to foster a reduction of atmospheric pollution and, consequently its social costs [4].

An operative integration of LCA and ExternE parameters in energy technology models was performed in the framework of the NEEDS Integrated Project [5], developed under the EU Sixth Framework Program, implementing an innovative modelling platform, the NEEDS-TIMES Pan European Model (NEEDS-TIMES PEM), for the assessment of policies on energy and environmental themes at EU wide level with a country level detail. This multi-region platform, based on the MARKAL-EFOM TIMES System models generator (TIMES) is made up by the energy system models of 30 European countries (EU27 plus Iceland, Norway and Switzerland), linked by electricity trades and includes as new inputs key LCI data (Life Cycle Inventories) and externalities (i.e. the most important emissions, materials, and damage costs) allowing to take into account their contribution under different scenario hypotheses.

In this paper, the methodology approach is described and the main results relative to the internalisation of external costs of local and global air pollutants are presented with reference to the Italy case study.

2. Methods

2.1. The NEEDS-TIMES energy models

The overall objective of the NEEDS Integrated Project was to evaluate the full costs and benefits (i.e. direct + external) of energy policies and of future energy systems, both at the level of individual countries and for the enlarged EU as a whole.

To this issue, a suited modelling platform, the NEEDS-TIMES Pan European model, was implemented, utilising the ETSAP-TIMES models generator [6], a high level computer code that generate technical-economic models of energy environment systems for target-oriented integrated policy analysis and planning. TIMES is a bottom-up models generator based on mathematical programming (least-cost optimisation) that allows determining the optimal configuration of energy systems by scenario, considering technology development and vintage. Costs are typically actualised to a base year that is the reference year for statistical data on energy balance and technology stock.

The NEEDS-TIMES country models are built up on a common basic structure that schematises the Reference Energy System—RES, representing the fundamental energy and materials flows by sector (Residential, Commercial and Agriculture—RCA, Industry—IND, Transport—TRA, Electricity and Heat production—ELC, and Energy supply—SUP) and allowing their straightforward multi-region integration into the Pan European model. Together with the RES, that determines the "shape" of the energy system, the data files containing the technical, socio-economic and environmental information on the modelled energy systems constitute an integral part of the NEEDS-TIMES model.

Data files are made up by Excel spreadsheets and managed by the Versatile Data Analyst—VEDA FE/BE [7,8] user interface, that allows also running the models and analysing the output tables. This structure assures a full transparency of data and assumptions and their user-friendly management that ease models improvement and the implementation of users' constraints. The primary data sources for calculating the basic demands for energy services and the information on the technology stock are the Eurostat data [9] that were complemented by national statistics (for instance [10,11]). The reference year is 2000 and the analysed time horizon is 2000–2050, divided into 5-year time intervals (except for the first two periods respectively 1- and 2-year long). A 4% money discount rate was utilised for all sector to discount the costs to the reference year. The demand projections of sectoral final energy demand over the time horizon were estimated by CES-KUL [12] with the use of GEM-E3 model. More exhaustive information on the models features can be found in Kypreos et al. [13].

2.2. Computation of the environmental damages

Externalities or external costs, as well known, allows a monetary evaluation of the damages caused by pollutant activities on human health and environment in terms of socio-economic costs to be borne, which is helpful in the design of energy and environmental policies allowing incorporating these costs in the price of resources via taxes, subsidies or other economic instruments [4]. The main reference for methods and results of externalities estimation is actually represented by the ExternE European Research Network [3]. In the NEEDS project approach, updated values estimated by using the ExternE methodology (carried out by two dedicated research streams using the EcoSense model [14,15]) were integrated into the input data of the energy models, in order to take externalities into account in decision making processes based on a least-cost optimising approach and to point out their role in the achievement of strategic policy targets. In particular, in the NEEDS-TIMES models damage cost functions are utilised to extend the concept of an emission tax by modelling more accurately the assumed cost of damages due to emissions of a pollutant [16].

Operatively, the integration is performed by including in the input data of each country model a damage parameter for each considered air pollutant emission from the energy system (both global – CO_2, CH_4, N_2O – and local pollutants – SO_2, NO_x, NMVOC, PM10 and PM2.5) [17]. These coefficients, included in an additional file, are represented by the damage costs associated to one unit of each substance emitted in that country (e.g. the damage cost due to one tonne of SO_2 emitted in France) and should be specialised to take into account the site-dependency. At Pan European level, all the damage costs associated to each country are considered, reporting those values in a suited file.

As concerns the mathematical formulation, in a given time period, and for a given pollutant, the damage cost is modelled as follows [16]:

$$\mathrm{DAM(EM)} = \alpha \cdot \mathrm{EM}^{\beta+1} \quad (1)$$

where:

- DAM is the damage cost in the current period for EM emission;
- EM is the emission in the current period;
- $\beta \geq 0$ is the elasticity of marginal damage cost to amount of emissions; and
- $\alpha > 0$ is the marginal damage cost per unit of emission at some reference level of emissions obtained from RS1b by means of dose–response studies.

Denoting the marginal cost at the reference level MC_0, the following holds:

$$MC_0 = \alpha(\beta + 1)EM_0^{\beta} \quad (2)$$

where EM_0 is the reference amount of emissions. Therefore, expression (1) may be rewritten as:

$$DAM\,(EM) = \frac{MC_0 EM^{\beta+1}}{(\beta + 1)EM_0^{\beta}} \quad (3)$$

The modelling of damage costs via Eq. (3) introduces a nonlinear term in the objective function if the parameter β is strictly larger than zero. This in turn requires that the model has to be solved via a Non Linear Programming (NLP) algorithm.

With concern to the optimisation process, the environmental damages can be thus computed in two different ways [16]:

- Ex post: when damage functions provide an economic evaluation of environmental damage without feedback into the optimisation process.
- Ex ante: in this case damage functions are part of the objective function and are taken into account in the optimisation process.

In both approaches, it is assumed that:

- Emissions in each country (region) cause damage only in the same region or, due to trans-boundary pollution, also in other regions;
- All damage costs are allocated to the polluters in the source region, in accordance with the Polluter Pays Principle, or Extended Polluter Responsibility;
- Damages are not delayed, nor are they cumulative (damages in a given time period are linked to emissions in that same period only);
- No cross impacts are considered (damages due to several pollutants are the sum of damages due to each pollutant).

For the Italy case study both ex post and ex ante evaluations were performed with a LP approach, considering $\beta = 0$ (no elasticity allowed).

3. The case study

The modelling assumptions of the NEEDS-TIMES Italy model are extensively described in [18,19]. Here a brief summary of the main features is reported.

3.1. Energy consumption

Energy dependence is a major criticality for Italian economic development. In 2000 (elaborations on Eurostat [9] data) the national primary production was 1018 PJ (of which 51% natural gas, 17% crude oil, 14% hydropower, 12% geothermal energy), against a total import of 7322 PJ (mainly crude oil: 48% and natural gas: 27%) and only 867 PJ of total export (gas/diesel oil: 37%, residual fuel oil: 22%, and gasoline: 20%).

In the same year, the final energy consumption was 5430 PJ, of which 34% Transport, 33% Industry, 21% Residential, 9% Commercial and 2% Agriculture. As concern fuel mix, oil products were prevailing (42%) followed by natural gas (30%), electricity (18%), heat (6%), coal (3%) and renewables (1%).

3.2. Air emissions

Emissions from fuels combustion at the base year 2000, as represented in the NEEDS-TIMES Italy model, are reported in Table 1.

The carbon dioxide emissions are mainly caused by Electricity and Heat as well as Transport (accounting for 28% each). Transport is also the main producer of NO_x, CO and NMVOC emissions (accounting respectively for about 62%, 76% and 86% of the total emissions), whereas almost 50% of the total SO_2 emissions are produced by Electricity and Heat, and 22% by Supply.

As concerns the GHG emissions from processes (main sources: [20,21]), about 30 Mton of CO_2 are emitted by Industry, 734.5 kton of CH_4 (17 Mton of CO_{2eq}) by Agriculture, and 103.56 kton of N_2O (31 Mton of CO_{2eq}) by Agriculture (75%) and Industry (25%).

3.3. National renewables potentials

Renewable resources have a key role in reducing the atmospheric pollution. Therefore, a preliminary evaluation of their potential is necessary to estimate their future deployment in the long term scenario analysis. The national potential of electricity production in 2020 and 2050 is reported in Table 2. In particular, the 2020 values are taken from the "Position Paper" of the Italian Government [22], whereas the 2050 values were estimated taking into account other official available documents (for instance, [23]).

As concerns hydrogen, great expectations have been raised in the energy sector about its possible use for powering vehicles as a surrogate of oil products, even though these expectations have not lead to a practical outcome so far. Thus, hydrogen vehicles were made available from 2010, as a technology option in the transport sector.

Table 1
Emissions from fuel combustion in 2000.

Sector/emission	CO_2 (Mton)	CH_4 (kton)	N_2O (kton)	NO_x (kton)	SO_2 (kton)	CO (kton)	NMVOC (kton)
Electricity and Heat	115.7	6.9	4.5	119.5	306.8	32.1	7.1
Supply	16.3	2.2	0.6	36.5	142.1	22.69	2.2
Industry	97.7	5.9	5.1	141.8	87.8	336.5	5.3
Transport	114.2	38.6	10.3	777.4	91.8	3,137.3	744.9
Residential	52.1	19.5	5.9	61.5	22.6	461.8	69.2
Commercial	16.9	1.9	1.6	15.0	5.3	10.9	1.0
Agriculture	8.1	2.4	2.9	106.3	2.1	114.6	33.5
Total	421.6	77.4	30.9	1258	658.5	4,115.5	863.2

Table 2
Potential electricity production by renewable energy source (TWh).

(TWh)	2020	2050
Hydro	43	65
Wind	23	28
Biomass		
Wood	7.6	7.6
Waste	3	3
Biogas	1.8	1.8
Geothermic	9.7	9.7
Solar		
PV	7.5	31
Hot water	2.2	2.9

3.4. CO_2 reduction potential

Carbon capture and storage processes (CCS) and afforestation were included into the NEEDS-TIMES Italy model to evaluate their potential contribution to the reduction of CO_2 emissions, exploring thus different possible mitigation paths.

In fact, CCS technologies could have a very promising role in the achievement of mitigation strategies, as outlined also by the European Commission Strategic Energy Technology Plan (SET-Plan [24]). Although these technologies are fairly well known and have already been tested on a small scale, they still have very high costs, estimated about 50–90 $/ton CO_2 [25], where on average two-thirds is accounted for the capture of CO_2, 10% by transport and 20% by storage [26].

According to the studies carried out by the Italian National Institute for Geophysics and Vulcanology (INGV) in Italy there are about 100–200 safe geological sites, with a total capacity of storage estimated in 20–30 Gton of CO_2 [27].

Concerning afforestation, according to the national law n. 120/2002 that ratifies the Kyoto Protocol, the estimated national potential of CO_2 absorbed by forests in 2010 is about 10 Mton CO_{2eq} whereas the estimated national potential in 2050 reaches 18 Mton CO_{2eq}.

3.5. Integration of external costs into the Italian model

3.5.1. External costs of local air pollutants (LAP)

The external costs related to local air pollutants (LAP) refer to NH_3, NMVOC, NO_x, PM_{coars} (PM10), PM2.5 and SO_2. The data integrated in the Italian model, were calculated starting from updated values provided by IER [14,15]. In particular, following their recommendations, the values related to "high height of release" were used for power plants whereas for all the other technologies it was referred to the values related to an average height of release. The data relative to the different kind of impacts (human health, crop yield loss, damage to building materials, loss of biodiversity caused by acidification and eutrophication) were further aggregated and discounted to the year of release with a 4% discount, obtaining the annual values of the cumulative external costs reported in Table 3, that were inserted into the model data input for each period.

3.5.2. External costs of greenhouse gases (GHGs)

The cost evaluation of greenhouse gases emissions and climate change is a very contentious issue, with high inherent uncertainties. Therefore, available CO_2 (and consequently, GHG) external costs spans in a very wide range of cost estimations (from about 10 €/ton CO_2 to a hundred of €/ton CO_2) due to the underlying hypotheses (e.g. Kuik, Anthoff, and Nordhaus [15]). After an exhaustive literature review and taking into account the results coming from the NEEDS project internal discussions, two sets of reference values were identified (Table 4):

- *Ambitious scenario*, updated values that take into account the recent policy decisions, representing a compromise between the combination of the values proposed by Research Streams 1b ("more ambitious scenario") and Research Streams 1a ("preferred scenario") [28] inside NEEDS project.

Table 3
External costs of LAP in the NEEDS-TIMES Italy model (Euro/ton).

	Power plants (high height of release)					Other technologies (unknown height of release)				
	NMVOC	NO_x	PM10	PM2.5	SO_2	NMVOC	NO_x	PM10	PM2.5	SO_2
2001	639	6,602	650	13,404	6,566	639	8,362	1,730	29,303	7,434
2005	670	7,034	696	14,339	7,019	670	8,907	1,851	31,347	7,947
2010	712	7,617	757	15,600	7,629	712	9,640	2,014	34,104	8,640
2015	343	9,175	827	16,977	8,773	343	11,411	2,190	35,305	9,938
2020	364	9,933	900	18,470	9,540	364	12,353	2,382	38,409	10,808
2025	386	10,757	979	20,094	10,375	386	13,377	2,592	41,787	11,755
2030	411	11,653	1,065	21,861	11,284	411	14,492	2,820	45,462	12,785
2035	424	12,133	1,111	22,806	11,770	424	15,089	2,941	47,427	13,335
2040	438	12,633	1,159	23,792	12,277	438	15,711	3,069	49,477	13,910
2045	452	13,155	1,209	24,821	12,805	452	16,359	3,201	51,616	14,510
2050	467	13,699	1,261	25,894	13,357	467	17,036	3,340	53,847	15,135

Table 4
GHG external costs (Euro/ton of CO_{2eq}).

Scenarios	2010	2015	2020	2025	2030	2035	2040	2045	2050
Ambitious									
CO_2	23.5	31	46	51	74	87	110	146	198
CH_4	493.5	651	966	1,071	1,554	1,827	2,310	3,066	4,158
N_2O	7,285	9,610	14,260	15,810	22,940	26,970	34,100	45,260	61,380
Realistic									
CO_2	23.5	27	29	32	34	37	50	66	77
CH_4	493.5	493.5	567	609	672	714	777	1,050	1,386
N_2O	7,285	7,285	8,370	8,990	9,920	10,540	11,470	15,500	20,460

Table 5
Discounted system's cost with and without damage (MEuro).

Scenarios	Total discounted system's cost (MEuro)						
	Ex post				Ex ante		
	Energy system cost	Damage		Total cost	Energy system cost	Damage	Total cost
BAU_GHG	5,158.83	GHG	607.81	5,766.64	5,196.27	531.46	5,727.72
BAU_LAP	5,158.83	LAP	584.32	5,743.15	5,224.20	454.47	5,678.67
BAU_LAP_GHG	5,158.83	GHG and LAP	1,192.13	6,350.96	5,245.62	999.24	6,244.86
Kyoto_LAP	5,243.57	LAP	530.91	5,774.47	5,273.33	474.94	5,748.27

- *Realistic scenario*, values derived by the results of the scenario analysis with the NEEDS TIMES Pan EU model [29] that are in line with the values proposed by Anthoff in the World EW scenario [30] and Watkiss et al. [31].

Also in this case, as done previously for the external costs of local air pollutants the values included in the NEEDS-TIMES models were discounted to the year of emission.

4. Scenario analysis

The scenario analysis was mainly addressed to emphasise the policy implications of external costs in terms of model's choices as well as to evaluate the effects of the ratification of the Kyoto Protocol. Therefore, the following scenarios were defined, whose macroeconomic and energy price background assumptions are in line with DG TREN 2005 projections [32–34]:

- BAU (Business as Usual): The baseline scenario, in which all the exogenous assumptions around drivers, energy prices and policies follow a rather business as usual trend. No climate policy is considered.
- BAU_GHG: Baseline scenario assumptions with the internalisation of the externalities related to CO_2, CH_4 and N_2O only, using the "Ambitious scenario" values.
- BAU_LAP: Baseline scenario assumptions with the internalisation of the externalities related to local air pollutants only (SO_2, NO_x, NMVOC, PM10 and PM2.5).
- BAU_LAP-GHG: Baseline scenario assumptions with the internalisation of the externalities on both local and global air pollutants, including CO_2 ("Ambitious scenario" values).
- Kyoto_forever: A climate policy scenario aimed to achieve the national Kyoto Protocol's target (−6.5% of GHGs in the period 2008–2012 compared to the 1990 values[1]). Thus, starting from the values of the reference scenario, a reduction of 448 Mton of CO_{2eq} was imposed yearly from 2010 to 2050 to model the GHGs stabilisation on the full time horizon. No tradable permits or flexible mechanisms are allowed to achieve the prefixed −6.5% target.
- Kyoto_LAP: The internalisation of the externalities on local air pollutants (SO_2, NO_x, NMVOC, PM10 and PM2.5) was added to the Kyoto_forever scenario's assumptions.

In order to compare the effects of the internalisation of damage costs on the total system's cost, the scenarios including externalities on pollutants were analysed with both the ex post and ex ante approach, obtaining the results reported in Table 5.

From an economic point of view, the internalisation of damage costs (ex ante approach) induces a general increase of energy system costs due to new investments in more efficient technologies with a lower environmental impact. Nevertheless, including the damage, the total discounted system's cost shows a decrease that spans from 0.5% in Kyoto_LAP up to 1.7% in BAU_LAP_GHG.

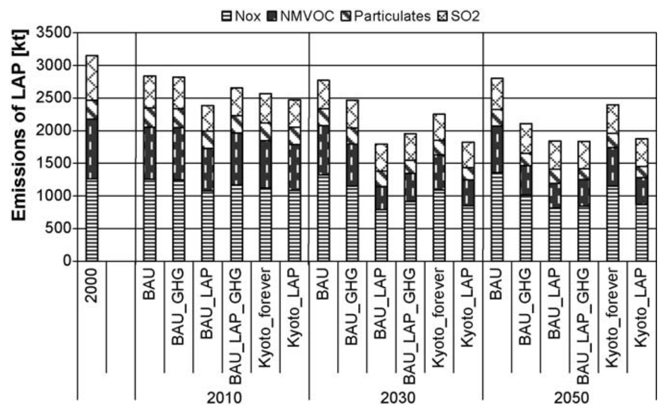

Fig. 1. Local air pollutants emissions (kton).

As concerns the air pollutant emissions (Fig. 1), a higher reduction of LAP is obtained in BAU_LAP respect to BAU_LAP_GHG (respectively 25% and 20% on the overall time horizon). Therefore, the combined policy (BAU_LAP_GHG), being less effective to reduce LAP, turns out to be more expensive, with an estimated overall avoided damage of about 193 MEuro whereas the sum of the avoidance costs of BAU_LAP and BAU_GHG is about 206 MEuro.

Nevertheless, it proves to be more suited to pursue a joint reduction of both LAP and GHGs.

In fact, as shown in Figs. 1 and 2, in BAU_GHG a 7.8% reduction of LAP emissions and a 15% reduction of GHGs is achieved without any policy on them. On the contrary, in BAU_LAP there is a 25% increase of GHGs. This consistent variation is, mainly caused by the increase of natural gas consumption due the production, by a Fischer–Tropsch process, of a synthetic diesel characterised by a very low sulphur and aromatic content [35] and to the absence of CCS.

On the other hand, the internalisation of the externalities on both LAP and GHGs foster a higher decrease of both local and global

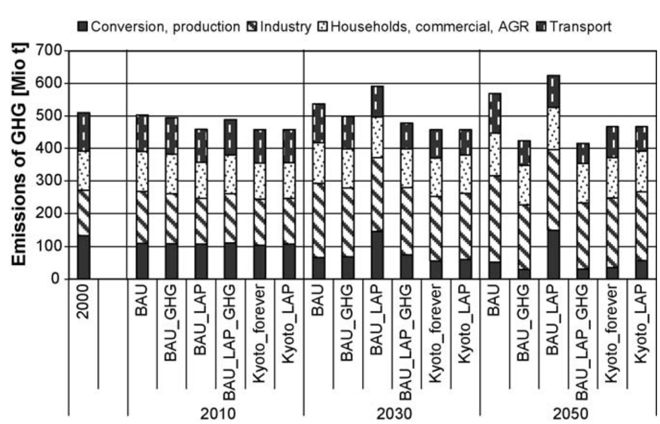

Fig. 2. Total GHG emissions (Mton CO_{2eq}).

[1] Total emission WITHOUT land-use, land-use change and forestry.

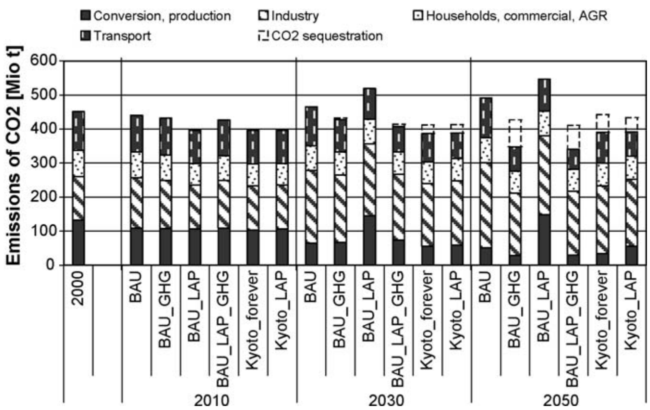

Fig. 3. Carbon emissions per sector (Mton/year).

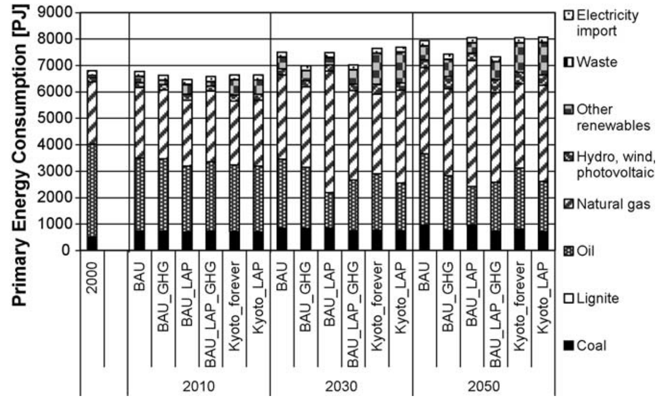

Fig. 4. Primary energy consumption (PJ).

pollutant emissions (in BAU_LAP_GHG the LAP and GHG reduction percentages being respectively −42% and −14%).

An in-depth examination of the local air emission pollutants (NO_x, SO_2, NMVOC and particulates) shows that a remarkable reduction of NMVOC (−59% in BAU_LAP) followed by a 35% reduction of NO_x in BAU_LAP, 42% reduction of particulates in BAU_LAP_GHG and 38% reduction of SO_2 in BAU_LAP_GHG. It is worthy to note that the abatement of LAP emissions is obtained entirely by fuel switching and technology substitution as no end of pipe technologies were inserted into the model, in order to foster the transition of the system towards a more efficient configuration.

As concerns CO_2 emissions (Fig. 3) the internalisation of GHG externalities (BAU_GHG scenario) has proven to be effective on the long term but not in the short term, highlighting that CO_2 external costs can influence the energy-technology mix only at their highest values. In particular, the minimum of CO_2 emissions in 2050 is achieved in BAU_GHG (−21% respect to the emissions of the reference year of which 23% due to CCS processes), with the highest contribution from the conversion sector, whose emissions decrease about 76%. In this case, also the CO_2 emissions from Transport show a substantial decrease (about −37% respect to the emissions of the reference year) due mainly to the use of biofuels.

As concerns Households, Commercial and Agriculture, a 4% decrease of CO_2 emissions is observed already in the BAU scenario. This percentage increases to about 13% with a Kyoto policy (Kyoto_forever) and to 17% in BAU_LAP_GHG.

On the contrary, Industry shows increasing CO_2 emissions in all scenarios (from 95% of BAU to 43% of BAU_GHG) because of a larger use of natural gas (almost doubled) consequent to the high increase of energy demand (about 72% for energy intensive industries and 32% for non energy intensive ones). In particular, natural gas consumption reaches its highest value in Kyoto_LAP (from 906 PJ in 2000 to 2412 PJ in 2050).

From these results it is therefore possible to affirm that GHG emissions reduction on the long term is fostered by either internalisation of externalities and the Kyoto cap, nevertheless a direct exogenous constraint allows achieving a more substantial and stable reduction also at short term.

Table 6 summarizes the effects of different scenarios assumptions on the overall emissions of the main pollutants, highlighting that, also on the full time horizon the internalisation of external costs on local air pollutant combined with a Kyoto cap (Kyoto_LAP) is more effective to reduce both GHG and LAP emissions. Moreover, as concerns the total discounted system's cost, Kyoto_LAP allows achieving an 8% reduction of the total discounted system's cost respect to BAU_LAP_GHG (ex ante evaluation).

In the following the main changes due to the internalisation of external costs are illustrated in terms of energy mix and electricity production.

According to energy demand projections, primary energy consumption increases about 17% from the initial 6799 PJ in the BAU scenario. Even though a generalized increasing trend can be observed for all the scenarios, a different behavior characterise the different modelling choices (Fig. 4). In fact, a higher increase can be noticed for BAU_LAP and Kyoto_LAP (about 20%) whereas a lower increase is noticed for BAU_GHG and BAU_LAP_GHG (respectively about 11% and 9%).

Energy demand is fulfilled by different fuel mixes that take into account the different boundary conditions. In particular, comparing the values obtained for BAU_LAP and Kyoto_LAP with BAU in 2050, it can be noticed in both the scenarios a decrease of oil consumption (respectively −46% and −30%) and an increase of natural gas consumption that is stronger in BAU_LAP (+45% against the +12% of Kyoto_LAP). In Kyoto_LAP there is also a decrease of coal (−25%) and a huge increase of renewables (+32% for hydro, wind and photovoltaic and +136% for other renewables) to comply with the constraint on GHGs.

Analogously, in BAU_GHG and BAU_LAP_GHG it can be noticed a sharp decrease of coal (around 20%) and oil use (respectively −24% and −31%), natural gas use is almost constant and there is a remarkable increase of endogenous production by hydro, wind and photovoltaic in electricity production (respectively +59% and +75%) resulting in a decrease of electricity imports (−6% and −8%).

Table 6
Pollutant emissions by scenario from 2000 to 2050 (Mton).

Scenario	Total emissions (Mton)				
	GHG	SO_2	NO_x	VOC	Particulates
BAU	28,191	24.70	68.40	40.93	14.60
BAU_GHG	26,335 (−6.6%)	24.17 (−3.3%)	63.15 (−8.8%)	35.52 (−14.2%)	13.42 (−7.1%)
BAU_LAP	31,503 (+11.7%)	22.97 (−8.1%)	47.97 (−30.7%)	25.98 (−37.2%)	13.27 (−8.1%)
BAU_LAP_GHG	25,398 (−9.9%)	22.32 (−10.7%)	53.09 (−23.3%)	30.93 (−25.3%)	*11.66 (−19.2)*
Kyoto_forever	25,485 (−9.6%)	23.41 (−6.3%)	60.75 (−12.2%)	33.40 (−19.3%)	13.14 (−9.0%)
Kyoto_LAP	25,476 (−9.6%)	*22.33 (−10.6%)*	*51.43 (−25.7%)*	*28.85 (−30.3%)*	11.50 (−20.4%)

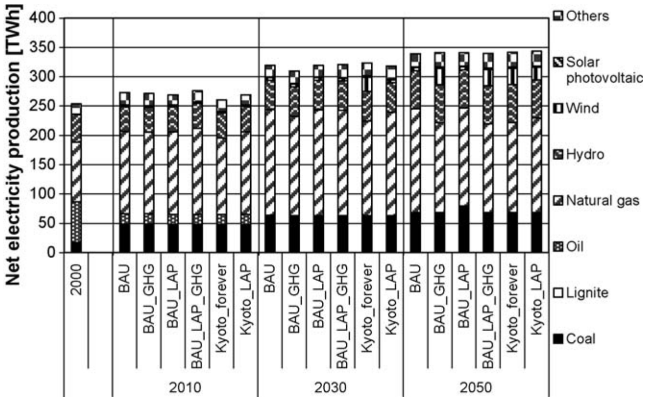

Fig. 5. Net electricity generation (TWh).

An in-depth analysis of the electricity production modes (Fig. 5) highlights an overall increase of about 34% in the endogenous production (from 254 TWh of year 2000 to 343.6 TWh in 2050 for Kyoto_LAP).

Significant variations of fuel mix can be observed along the time horizon in compliance with different modelling assumptions. In the optimised energy system configuration, oil is substituted by natural gas and coal from 2030 onwards (in 2050 natural gas increases up to 74% in BAU). Among renewables a remarkable increase of wind can be noticed (from 0.6 TWh in 2000 to a maximum of 27.8 TWh in BAU_GHG).

In 2050, electricity is still produced half by natural gas (from 45% to 52%), but there is a noticeable contribution of renewables (that ranges from 28% to 35%), and coal with CCS (about 20%). Among renewables, hydro and other renewables contribution is almost constant (respectively about 20% and 7%), whereas there is a significant increase of wind (up to 8%). Solar photovoltaic can hardly penetrate the market, with an estimated contribution around 1%. Some main differences can be noticed among the scenarios with and without the constraints on GHGs (e.g. BAU and BAU_LAP versus BAU_GHG, BAU_LAP_GHG, Kyoto_forever; Kyoto_LAP). In fact, natural gas consumption decreases around 45% whereas the renewables contribution is maximum (around 35%) with the Kyoto constraint or considering the externalities on GHGs. On the contrary, natural gas share is about 52% in the BAU scenario and the highest share of coal (24%) is achieved in BAU_LAP, both scenarios corresponding to the lowest value of wind (2%).

Final energy consumption increases in all scenarios from 2000 to 2050 more than 20% (Fig. 6), reaching the maximum variation in BAU (+25%).

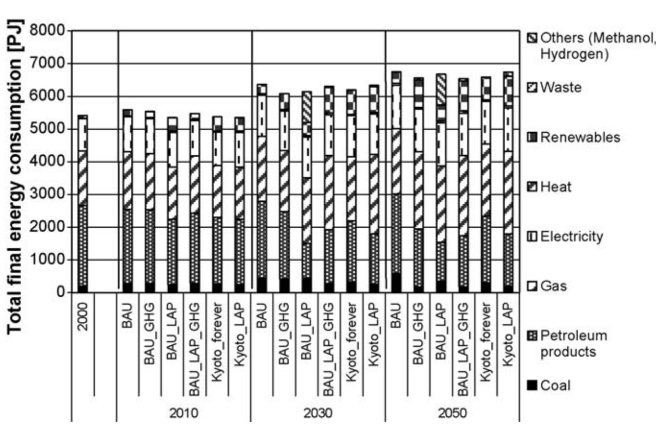

Fig. 6. Total final energy consumption (PJ).

Table 7
Impact of internalisation on the renewables share in gross final energy consumption (%).

Scenario	% of renewables in final energy consumption			
	2000	2010	2020	2050
BAU	4%	5%	7%	12%
BAU_GHG		5%	11%	22%
BAU_LAP		5%	6%	13%
BAU_LAP_GHG		5%	15%	24%
Kyoto_forever	4%	10%	16%	20%
Kyoto_LAP		9%	16%	21%

As concerns fuel use, in the reference year oil products have the highest share (46%), followed by natural gas (31%) and electricity (18%). On the long term, these are still the most used fossil fuels in all scenarios, but significant differences could be noticed in the fuel mix. In particular, oil products consumption decreases in all scenarios, with a 18% minimum share in BAU_LAP for 2050 whereas electricity consumption is slightly increased to 20%. On the other hand, natural gas consumption shows a different behavior along the scenarios, with a share ranging from 30% in BAU to 38% in Kyoto_LAP. Renewables consumption also increases in all the scenarios, its share in 2050 being around 14% in BAU_LAP_GHG and Kyoto_LAP. The use of biofuels is strongly enhanced in BAU_LAP (about 938 PJ) fostered by a large use of FT-diesel in transport sector to decrease local pollutant emissions.

The effects of internalisation of externalities in terms of renewables share in gross final consumption of energy are summarized in Table 7. It can be seen that introducing externalities without any specific constraint on GHG is not sufficient to speed up the use of renewables. In fact, the BAU scenario is far from the objectives set by the EU for increasing the share of renewable energy. The 17% target by 2020 is hardly achieved in the scenarios Kyoto_forever and Kyoto_LAP, whereas in 2050 the RES share increases above 20% only in the scenarios with an exogenous constraint on GHGs, achieving its maximum share in BAU_LAP_GHG (24%).

5. Conclusive remarks

This study was aimed to test in a national case study what are the effects of air pollution-related external costs on the optimal energy system configuration in the medium-long term (2050). To pursue this aim, the NEEDS-TIMES Italy modelling platform was adopted, integrating in the energy system's data input the most recent values of externalities related to local and global air pollutants (NO_x, SO_2, VOC, particulates and CO_2, CH_4, N_2O) made available by the damage costs evaluation experts within the NEEDS project.

Scenario analysis was carried out to assess the prospects of future developments and the possible implications of alternative decision pathways of a national energy system when air pollutants externalities are taken into account, evaluating the winning policy strategy for GHGs reduction between damage costs accounting and a carbon constraint according to the Kyoto national commitments.

Results obtained for the Italy case study show that the internalisation of damage costs pushes the system towards a more efficient technology configuration leading, in general, to a reduction of air pollutants and to an increase of the total system cost.

In particular, a 25.2% reduction of local air pollutants can be achieved in 2050 introducing their related LAP externalities (and only −20% if LAP and GHGs externalities are jointly introduced).

As concerns greenhouse gases reduction, introducing externalities on local air pollutants has a negative effect on the levels of

CO_{2eq} (+22% in 2005, against a +12% of the baseline trend) whereas GHGs externalities causes a consistent reduction of CO_{2eq} on the long term, reaching -17% in 2050 (and -19% when both LAP and GHGs externalities are taken into account) although a less relevant reduction can be observed on the short term. On the contrary the carbon cap (in both the Kyoto scenarios) allows a more or less constant reduction of the GHGs levels by 2010 onwards, accounting for -8% in 2050.

Thus, if the stakeholder perspectives are mainly focused on the long term, then the introduction of joint externalities on both LAP and GHGs represent the most effective choice, in terms of air pollution reduction and total energy system costs (inclusive of the avoided damages). On the other hand, a post-Kyoto policy can be achieved only imposing an exogenous constraints on GHGs.

Acknowledgements

This work was performed in the framework of the EU NEEDS project (Contract Number 502687) supported by the Directorate General for Research of the European Commission in the context of the VI Framework Programme, Priority 6.1: Sustainable Energy Systems, Sub-priority 6.1.3.2.5: Socio-economic tools and concepts for energy strategy.

The authors would like to thank Prof. Denise Van Regemorter (CES KULeuven, Belgium) for her kind support and helpful discussions on the integration of externalities into the TIMES models.

Views expressed herein are those of authors and can therefore in no way be taken to reflect the official opinion of the European Commission.

References

[1] Energy Technology Systems Analysis Programme (ETSAP). Available at: http://www.etsap.org.
[2] Society of Environmental Toxicology and Chemistry (SETAC). Available at: http://www.setac.org/.
[3] Externalities of Energy (ExternE). Available at: http://www.externe.info/ and http://externe.jrc.es/.
[4] European Commission. ExternE—Externalities of energy. Methodology 2005 Update. EUR 21951 EN. Office for Official publications of European Communities, Luxemburg. ISBN 92-79-00423-9; 2005.
[5] New Energy Externalities Development for Sustainability (NEEDS). Available at: http://www.needs-project.org/.
[6] Loulou R, Remme U, Kanudia A, Lehtila A, Goldstein G. Energy Technology Systems Analysis Programme – Documentation for the TIMES Model – Part I: TIMES concepts and theory; 2005. Available at: http://www.etsap.org/Docs/TIMESDoc-Intro.pdf.
[7] KanORS Consulting Inc. VEDA-FE User Guide—Version 1.5.11. Available at: http://www.kanors.com/userguidefe.htm.
[8] KanORS Consulting Inc. VEDA4 User Guide—Version 4.3.8. Available at: http://www.kanors.com/userguidebe.htm.
[9] The Statistical Office of the European Communities. Eurostat database. Available at: http://epp.eurostat.cec.eu.int.
[10] TERNA S.p.A. Statistical Data on Electricity in Italy—2005 (Dati statistici sull'energia elettrica in Italia—anno 2005). National Electricity Grid (Rete Elettrica Nazionale); 2006. Available at: http://www.terna.com.br/.
[11] Italian Ministry of Productive Activities. National Energy Balance—year 2000 (in Italian); 2001. Available at: http://dgerm.sviluppoeconomico.gov.it/.
[12] Van Regemorter D, Kanudia A. Projections of the demand of energy services for NEEDS. Internal Technical Report of the EU Integrated Project NEEDS—New Energy Externalities Developments for Sustainability; 2006.
[13] Kypreos S, Blesl M, Cosmi C, Kanudia A, Loulou, Smekens K, et al. TIMES-EU: a Pan European model integrating LCA and external costs. J Sustain Dev Plann 2008;3(2):1–15.
[14] The EcoSenseWeb. Available at: http://webeco.ier.uni-stuttgart.de/.
[15] Preiss P, Klotz V. User's manual and "Description of updated and extended draft tools for the detailed site-dependent assessment of external costs". Draft version 4. Stuttgart: University of Stuttgart Institute of Energy Economics and the Rational Use of Energy-IER; 2007.
[16] Lehtila A, Loulou R. TIMES Damage functions. Energy Technology Systems Analysis Programme. TIMES Version 2.0 User Note; November 2005. Available at: http://www.etsap.org/Docs/TIMES-Damage.pdf.
[17] Intergovernmental Panel on Climate Change (IPCC). Climate Change 2001. IPCC Third Assessment Report; 2001.
[18] Cosmi C, Di Leo S, Pietrapertosa F, Salvia M, Cuomo V. National reports—Italy. Deliverable 5.14 of the EU Integrated Project NEEDS "New Energy Externalities Developments for Sustainability"; October 2006.
[19] Cosmi C, Di Leo S, Loperte S, Macchiato M, Pietrapertosa F, Salvia M, et al. A model for representing the Italian energy system: the NEEDS-TIMES experience. Renew Sustain Energ Rev 2009;13:763–76.
[20] United Nations Framework Convention on Climate Change (UNFCCC), National greenhouse gas inventory data for the period 1990–2005. Available at: http://unfccc.int/ghg_emissions_data/items/3800.php.
[21] Kram T, Gielen DJ, Bos AJM, de Feber MAPC, Gerlagh T, Groenendaal BJ, et al. The Matter Project—integrated energy and materials systems engineering for GHG emission mitigation. ECN; 2001, Available at: ftp://ftp.ecn.nl/pub/www/library/report/2001/c01017.pdf.
[22] Department for European affairs. Secretariat of the Ministerial Committee for European affairs. Energia: temi e sfide per l'Europa e per l'Italia (in Italian). Position Paper of the Italian Government; 10 September 2007.
[23] White book for valorisation of renewable energy sources, CIPE deliberation 6 August 1999 (in Italian). Official Gazette of the Italian Republic 27-10-1999 n. 250.
[24] Commission of the European Communities. A European Strategic Energy Technology Plan (SET-plan) 'Towards a low carbon future'. COM (2007) 723 Final. Brussels, 22.11.2007.
[25] CO_2 capture& storage. IEA-Energy Technology Essentials; December 2006.
[26] Società Italiana di Fisica—SIF. Energy in Italy: problems and perspectives (1990–2020) (in Italian). In English is available: Highlights of Energy in Italy: problems and perspectives (1990–2020); April 2008.
[27] Moia F. Catalogo dei potenziali siti per lo stoccaggio geologico della CO_2. Workshop "Cattura e Sequestro della CO_2: risultati delle ricerche in ambito italiano" (in Italian). Catalogue of potential sites for geological storage of CO_2. Workshop "Capture and Sequestration of CO_2: results of research in Italy". Milan; 29 February 2008.
[28] Ricci A. NEEDS Internal Communication; 2008.
[29] Van Regemorter D, Cosmi C, Salvia M, Smekens K, KanudiaA, Loulou R, et al. T. D3.13-RS 2a Technical Report. Interim report on draft Pan European integrated model; November 2007.
[30] Anthoff D, Hepburn CJ, Tol RSJ. Equity weighting and the marginal damage costs of climate change. Ecol Econ 2009;68(3):836–49.
[31] Watkiss P, Anthoff D, Downing TE, Hepburn C, Hope C, Hunt A, et al. The social costs of carbon review—methodological approaches for using SCC estimates in policy assessment. London: Defra; 2005.
[32] Mantzos L, Capros P, Zeka–Paschou M. European energy and transport scenarios on key drivers. Brussels: Published by DG TREN; 2005.
[33] Kypreos S, Van Regemorter D. Scenarios to be generated with the TIMES model for NEEDS. NEEDS Internal working paper RS2a WP2.3; 27 February 2006.
[34] Kypreos S, Van Regemorter D, Guel T. NEEDS Internal working paper RS2a WP2.3. Key drivers for energy trends in EU: specification of the baseline and policy scenarios; 2006.
[35] Norton P, Vertin KD, Bailey BK, Clark N, Lyons DW, Goguen SJ, et al. Emissions from trucks using Fischer–Tropsch diesel fuel. SAE Technical paper series. ISBN 982526; 1998.

Filomena Pietrapertosa is researcher at IMAA-CNR since June 2005. Her main activity deals with energy system analysis using the ETSAP/IEA model generators to identify sustainable development strategies, with particular reference to the investigation on the contribution of renewables and high efficient technologies at local and national scale. In the last years she was fully involved in the FP6 Integrated Project NEEDS (2004–2009) where her work was mainly focused on analysing the Italian energy system and on integrating LCI (Life Cycle Inventory) data and externalities of air pollution into the TIMES-Italy model to provide a comprehensive computation of the environmental impacts of the energy systems as well as to internalise environmental damage costs (externalities). Actually she is involved in the IEE RES2020 and FP7 REACCESS Projects, where she works on further implementation of national and Pan-European energy systems models.

Carmelina Cosmi is researcher at IMAA-CNR since March 1998. Her current research interests' deal with energy system analysis with regard to the characterisation of the impact of anthropogenic activities on environment and multi-objective data analysis. Most of her research activities have been carried out in the framework of the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency (IEA). From 1994 she has being coordinating the research activities of the research line "Environmental modelling and planning", in the framework of the CNR Project "Sustainability of Environmental systems". She coordinated the IMAA-CNR activities performed in the framework of the FP6 IP NEEDS (2004–2009). Actually she is participating in the FP7 REACCESS CP, and she acts as scientific responsible of the IMAA-CNR participation to the IEE RES2020 Project.

Senatro Di Leo received the "Laurea" (MSc) degree in Environmental Engineering from the University of Basilicata (Potenza), Italy, in 2002. At present he is attending the last year of the PhD in "Methods and Techniques for Environmental Monitoring—Curriculum: Modelling for monitoring and the environment", at the University of Basilicata, Italy, in collaboration with IMAA-CNR. His PhD research focuses on the application of multivariate statistical techniques to partial equilibrium energy models outputs for improving the post-optimal analysis, allowing the users to characterise the data correlation structure and identify suited sustainability indicators in contrasting

development scenarios. He was fully involved in the FP6 Integrated Project NEEDS (2004–2009) and he is at present participating to the IEE RES2020 and VII FP REACCESS projects, contributing in the implementation, runs and scenario-results analysis of energy system models at national and Pan European level.

Simona Loperte received the ‘‘Laurea’’ (MSc) degree in Environmental Engineering from the University of Basilicata (Potenza), Italy, in 2003 with a degree thesis focused on the integration of LCA (Life Cycle Assessment) and MDA (Multivariate Data Analysis) for the environmental characterisation of power plants technologies. In 2007 she received a PhD in ‘‘Methods and Techniques for Environmental Monitoring—Curriculum: Modelling for monitoring and the environment’’, at the University of Basilicata, Italy, in collaboration with IMAA-CNR and the National Institute for the Physics of Matter (INFM). Her PhD activities were fully involved in the FP6 Integrated Project NEEDS, being finalised to the implementation of the Slovenian NEEDS TIMES model. These activities were further implemented till 2008 for the improvement of the renewables Slovenia energy system module in the framework of the EIE RES2020 Project.

Maria Macchiato is full professor of Physics at the University of Naples Federico II. Her main areas of interests concern: integrated methodologies for environmental planning; physical methodologies for the dynamical characterisation of geophysical and environmental processes; in situ measurements of atmospheric particulate to characterise heavy metal content; integrated chemical and geophysical techniques for soil monitoring in contaminated sites. In recent years, she has been coordinating several national and international projects concerning sustainable energy systems management and strategies for local and GHG emissions reduction. On behalf of INFM-CNR she has been responsible of the activities related to environmental modelling at DSF (Department of Physics Sciences) of the University Federico II of Naples. As concerns this thematic area, in the last years she was involved in the FP6 Integrated Project NEEDS (2004–2009), leading the participation of INFM-CNR.

Monica Salvia is researcher at IMAA-CNR since April 2001. In 2003 she was a Visiting Researcher at Centre for Social and Economic Research on the Global Environment (CSERGE, England), funded by a NATO-CNR fellowship. Her main areas of interests concern the field of modelling for waste management and energy systems. During these years, she has been taking part in several national and international research projects in the field of energy environmental planning, among which the IEA/Annex 33 ‘‘ALEP-Advanced Local Energy Planning (1997–2000)’’ and the FP6 Integrated Project NEEDS (2004–2009), participating actively at the ETSAP/IEA Programme activities. At now she is involved, in the IEE RES2020 Project and acts as scientific responsible of the IMAA-CNR participation to the REACCESS Project.

Vincenzo Cuomo, since 1993, is Director of the Institute of Methodologies for Environmental Analysis (IMAA) of the Italian National Research Council (CNR). Since 1975, the main topics of his research dealt with environmental physics, being focused on: earth observation by satellite; airborne and ground based instrumentation; development of new advanced sensors for observation from space; monitoring and control of environmental processes; protection against and prevention of natural risks; energy and environmental planning. He is member of Scientific Committee of Italian Space Agency, member of Scientific Committee of CNIT (National Inter-University Consortium for Telecommunications), chair of the Italian Coordination Group of Earth Observation, coordinator of projects funded by U.E., ESA, EUMETSAT, National Research Council, Italian Minister of University and Research, Italian Space Agency, Italian Institute of Physics Matter. In the framework of energy system analysis, he is the Italian delegate of the Executive Committee of ETSAP IEA Programme since 2005; furthermore in the FP6 IP-NEEDS (2004–2009), he was the scientific coordinator of the Research Stream 2a ‘‘Modelling Pan-European energy scenarios’’.